Energy Research and Development Division

**FINAL PROJECT REPORT**

# Commercial Demonstration of a Solar Thermal Heat Pump

## An Energy Efficient Hot and Chilled Water Solution for the Hospitality Industry

**California Energy Commission**

Gavin Newsom, Governor

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# PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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- Transportation

*Commercial Demonstration of a Solar Thermal Heat Pump* is the final report for the STHP Demonstration project (contract number PIR 12-023) conducted by Chromasun, Inc. The information from this project contributes to Energy Research and Development Division's Buildings End-Use Energy Efficiency Program.

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# ABSTRACT

Combining two previously successful technologies opens the door for substantial energy savings in commercial buildings. Using solar thermal panels to supplement a gas-driven single-effect gas absorption cycle provides both domestic hot water, and chilled water at unprecedented fuel efficiency levels. The solar thermal heat pump project targeted the hospitality industry to reduce owner and property operator energy costs. This project successfully designed, constructed, and operated a solar thermal heat pump at the JW Marriott Hotel in Desert Springs, California. Early results showed meaningful savings for hotels and other facilities. Chromosun, and its project partner, Energy Concepts Company will continue managing the installation to collect valuable design and operation information for the hospitality industry.

**Keywords:** solar thermal heat pump, STHP, absorption, ammonia-water, single-effect, concentrating solar, hospitality, domestic hot water, DHW, chilled water, CHW

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# EXECUTIVE SUMMARY

## Introduction

There are more than 5,000 hotels in California; and more than 52,000 in the United States, representing about 5 million rooms. Domestic hot water consumption is generally one of the largest building energy loads after air conditioning, especially in hospitality industry. The hospitality industry is a thin-margin business and always looking for economical ways to cut its operating costs. Using renewable resources, such as solar thermal heat pumps, to provide hot water can reduce energy costs for hotels, offering financial and environmental benefits.

## Purpose

The solar thermal heat pump (STHP) combines a solar thermal energy collector (panels) and a compression heat pump to simultaneously produce hot and chilled water. This technology could cut the user's typical operational cost almost in half for producing commercial-sized quantities of domestic hot water. The concept was initially aimed at the hospitality industry, however there is a variety of commercial facility applications wherever simultaneous consumption of large quantities of domestic hot water (used in showers, laundry, and kitchens) and chilled water (used for air-conditioning) are consumed.

Chromosun, and its project partner, Energy Concepts Company, combined two previously successful technologies into a unique approach to an old application, focused for the hospitality industry. Hotels generally have sufficient size and internal organization to successfully use the STHP technology.

## Process and Results

The Chromasun team designed, built, and operated a full-sized STHP at the JW Marriott at Desert Springs (a golf resort, located in Palm Desert, California) to learn from developing and operating this system, as well as provide hard data to the industry about the feasibility of the approach. The JW Marriott was selected because of its physical site conditions, hotel size, management interest and support, and proximity to a relatively large solar resource.

Chromasun manufactures the Micro-Concentrator (MCT) solar thermal panels, and Energy Concepts produces the gas absorption unit (HS-25), both have been successfully used in other applications. Chromasun's MCTs are a miniaturization of a successful utility-scale approach to generating high heat levels from the sun. Based on Fresnel mirror optics, the 11′x4′ panels are designed for commercial rooftop applications and are rated to provide up to 400°Fahrenheit heat. Chromasun has deployed the MCT in several direct-heating projects such as boiler pre-heat for a university student activity center

The STHP was completed within budget in mid-2016, and successfully demonstrated the basic technology in a live commercial setting. Operating the system and collecting the data helped Chromasun and its design team to understand several important lessons regarding handling the ammonia refrigerant charge, and adjusting to unexpected changes in the hotel's hot water demand profile.

Chromasun is using remaining match funds provided by the Southern California Gas Company to operate the STHP for two years, and engage the hospitality industry with technology transfer activities.

- In September 2015, the STHP was featured as a part of their annual roundup of "new technologies" for the HVAC business.
- Marriott International Engineering Conference (spring 2015): Marriott holds a tri-annual conference for the leadership of the engineering departments at its various properties world-wide. Numerous informal discussions still took place, and Chromasun received several inquiry phone calls as a result.
- Energy Concepts made a formal presentation at the ASHRAE 2017 conference about the STHP system. The session was well attended by specifying engineers and other channels that will be important for recommending the opportunity to clients who are in the midst of mechanical room upgrades.
- Marriott publishes an internal periodic newsletter for its engineering department heads. Chromasun expects to provide information and data for the next issue.
- The 2030 District whole Building Retrofit Tool (CBES Pro) was built using CBES adding 14 building types, 14 cities nationwide, four types of encentives and rebates, and deep retrofit packages.
- CEBS Pro was used to train 45 community college teachers at the Laney College sponsored workshop (January 2017).
- The CBeS Toolkit was expanded to support design and retrofit of zero-net energy buildings with key features including photovoltaics, batteries, daylighting, demand response and advanced heating, ventilation air conditioning systems.
- Among the benefits of hospitality trade associations to its members, are insights on how to operate more profitably. Chromasun will work with the California Hotel and Lodging Association to provide information about the STHP, including webinars for its members throughout the state. There also plans to expand the discussion to the national and international levels by reaching out to the American Hotel and Lodging Association (www.ahla.com/), and its European (www.hotrec.eu/) and international (http://ih-ra.com/) counter-parts.
- As of December 2018, more than 7,900 visitors had visited the CBES website.

## Benefits to California

The STHP has the potential to make positive environmental and economic impacts for California, especially hotel property managers and owners. Hotels, particularly the larger properties, rated 4 and 5 stars, also compete, in part, on the basis of environmental leadership. It is not uncommon for a facility's environmental story to operate as a "tie-breaker" when booking conventions and other large gatherings. These businesses also operate in a competitive industry with relatively narrow profit margins. Early project results of the STHP showed, for a typical hotel, a net annual savings of nearly 30,000 therms and about 55,000 kilowatt-hours of electricity. If the hotel pays an average of $0.75 per therm for natural gas and $0.12 per kWh for the energy cost of electricity during STHP operation, the annual cost savings would be nearly

$28,000. If all 5,000 California hotels (750,000 rooms) used this system, hotel operators could potentially save almost $14 million annually in energy costs. For the 52,000 hotels in the United States energy saving costs would be almost $158 million each year.

The technology as designed in this project could be adapted to many other commercial building applications, particularly those with high consumptive demands for hot water. The present design is not practical for residential applications.

Chromasun will continue to report to stakeholders, including Energy Commission, regarding the STHP's performance and its related activities to support commercialization of this technology.

# CHAPTER 1: Overview and Technical Background

## 1.1 The Problem to be Solved

Chromasun had the solar thermal heat pump (STHP) system available to the market in the US for more than a year prior to the California Energy Commission (Energy Commission) funding opportunity. While the system had a fair amount of interest from major hotel chains because of the potentially dramatic impact on utility bills, there were no immediate takers from a clearly interested hospitality industry. In addition to the lack of market familiarity with the technology, the large up front capital cost for the equipment and installation represented a significant market barrier. Solar tax and utility incentives, with a Power-Purchase-Agreement type financing structure, were positioned as strategies to mitigate some of these risks. Without having installation and experience base, however, these were not the short-term market barrier solutions originally anticipated. It came down to proven performance.

## 1.2 A Marriage of Two Successful Technologies

Chromasun, together with its partner, Energy Concepts Company (ECC), proposed to drive ECC's Helisorber (aka "HS-25") with Chromasun's MCT solar thermal concentrating collectors. The absorption unit – a single effect, ammonia/water system requires a 250°Farenheit (F) input driving temperature - a level easily achieved by Chromasun's MCTs. Together with a cofire/backup boiler for night-time use, the system was designed to provide for all of a hotel's 24/7 domestic hot water (DHW) load, along with supplemental chilled water (CHW) to help save electricity by improving chiller performance. High-level modeling found that the system could save 30-50% of the natural gas used for heating water, depending on the incumbent equipment's operating fuel efficiency. The CHW benefit would add to utility cost savings as a "free" side benefit.

### 1.2.1 MCTs (Micro-Concentrator Solar Thermal Collectors)

Chromasun's MCTs are a miniaturization of a successful utility-scale approach to generating high heat levels from the sun. Based on Fresnel mirror optics, the 11'x4' panels are designed for commercial rooftop applications and can provide up to 400°F heat. Chromasun has deployed the MCT in several direct-heating projects such as boiler pre-heat for a university student activity center (Figure 1).

**Figure 1: Installed Chromasun MCTs Solar Thermal Panels**

Photo Credit: Chromasun, Inc.

The MCT contains rows of parallel mirrors that rotate within the otherwise fixed-position panel to track the sun throughout the day (Figure 2), focusing the beams inside the box to a small heat receiver tube. Each panel has its own internal controller to track the sun's position at any time, enabling easy recovery of focus from passing clouds. During operation, the mirrors are aimed at a receiver tube which circulates water under pressure (up to 40 bar of pressure), allowing above-boiling-point temperatures to be transmitted to the heat load being served.

**Figure 2: Diagram of Chromasun MCT Internal Parts**

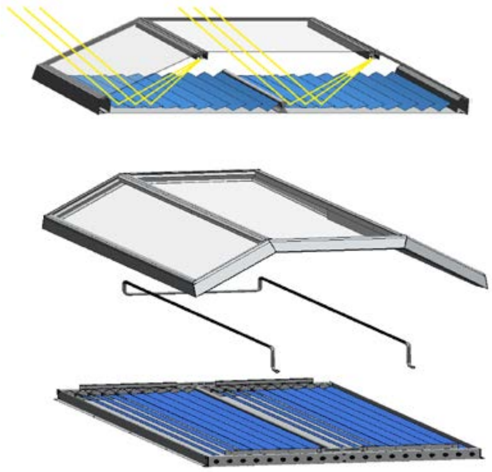


Photo Credit: Chromasun, Inc.

Each MCT panel is nominally rated at 2.2 kilowatt (kW) potential output (at 1,000 Watts / $M^2$ solar input) and is based on the amount of DNI (direct normal irradiance, specifically direct sunlight) received. Total yearly heat output depends mainly on the operating temperature, and the amount of DNI, which typically varies as a function of weather by much as 10% each year in a given location. Table 1 demonstrates a range of expected panel outputs for various temperatures and selected locations in California.

**Table 1: MCT Solar Panel Outputs**

| | MCT Annual Production ($MWh_{TH}$) | | | |
|---|---|---|---|---|
| **Location / Temp °C** | **50** | **80** | **120** | **170** |
| Bakersfield | 3.210 | 2.854 | 2.343 | 1.686 |
| Imperial Valley | 4.001 | 3.609 | 3.022 | 2.229 |
| Los Angeles | 2.797 | 2.439 | 1.933 | 1.298 |
| Modesto | 3.082 | 2.735 | 2.241 | 1.604 |
| Oakland | 2.417 | 2.125 | 1.714 | 1.200 |
| Palm Springs | 3.794 | 3.408 | 2.835 | 2.067 |
| Sacramento | 2.990 | 2.648 | 2.166 | 1.546 |
| San Diego, Montgom | 3.100 | 2.731 | 2.209 | 1.535 |
| San Francisco | 2.624 | 2.273 | 1.790 | 1.199 |
| San Jose | 2.925 | 2.570 | 2.074 | 1.445 |

Table Source: Chromasun, Inc.

### 1.2.2 Helisorber (Gas Absorption Chiller)

The gas-absorption part of the STHP system is provided by the "Helisorber", made by Energy Concepts Company (Figure 3). It is based on the single-effect ammonia-water gas absorption refrigeration cycle was first invented in 1857 as a chilling application, suitable for making what was called "artificial ice" at the time. It was the world's only major refrigeration cycle until after World War II when vapor compression began to erode its popularity. During the latter half of the 20th century, gas absorption receded into smaller niche markets as a cooling cycle.

**Figure 3: Energy Concepts Helisorber (HS-25) Gas Absorption Unit**

Photo Credit: Energy Concepts

Ammonia-water single effect gas absorption uses heat, not electricity, as its driving energy. The cycle is based on the extreme repulsion of water and ammonia at higher temperatures (for example >250F), and their extreme attraction to each other at relatively cooler temperatures. This creates the potential for large pressure differences. Gas absorption is similar to vapor compression in that both have an evaporator and condenser, along with high-and low-side pressures as the refrigerant pair flows through the cycle. The major difference is the mechanism of the compressor. In vapor compression, it is electro-mechanically driven. With gas absorption the process is heat-driven.

In the ammonia-water absorption, heat is applied to the generator (operating at 250°F in the Helisorber), which contains a solution of ammonia-water, and rich in ammonia (Figure 4). The heat causes high pressure ammonia vapor to desorb from the solution. The now high-pressure ammonia vapor flows to a condenser, this case cooled by make-up water for the hotel's DHW system. During this process, the ammonia vapor condenses into a high pressure liquid, releasing significant heat. This water is now hot (~130°F) and can be used in the hotel's DHW system. The two solutions (NH3/H2O pair and potable tap water) are separated by heat exchangers. Back inside the Helisorber, the high pressure ammonia liquid goes through a restriction, to the low pressure side of the cycle. This mixture, now at a lower pressure, boils or evaporates off some of the ammonia in the evaporator. This absorbs heat from whatever the evaporator is thermally tied to (in this case, the hotels' cooling system). Heat is removed from the building, making the existing chiller operate more efficiently. In the Helisorber, the now low-pressure vapor flows to the absorber, which contains a water-rich solution that came from the generator. At this point, the solution absorbs the ammonia vapor while releasing the heat of

**Figure 4: The Single-effect Ammonia-Water Gas-Absorption Process**

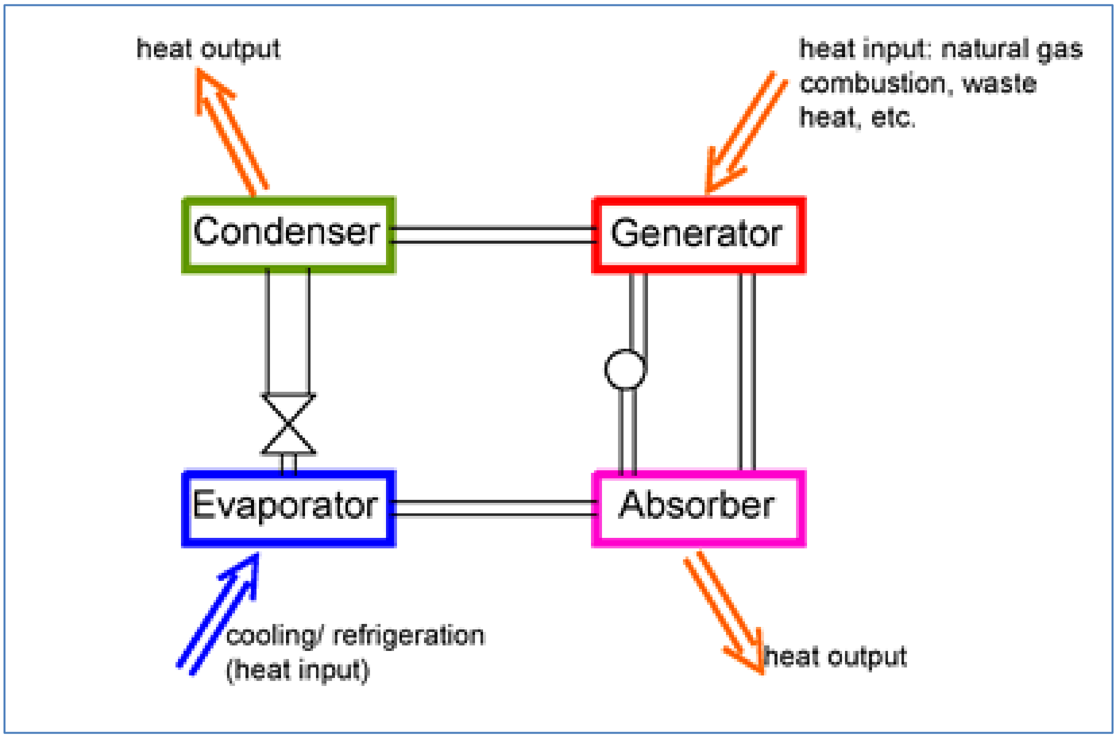



Diagram Credit: Energy Concepts

absorption. This byproduct heat is retained in the Helisorber and used to increase cycle efficiency. The solution in the absorber, now once again rich in ammonia, is pumped back to the generator, where it is ready to repeat the cycle. The process uses a very small amount of electricity to pump the solution around in the cycle, but the real work that creates the pressurization comes from heat, not electricity. This is in contrast to vapor compression where all of the work necessary to create that cycle's high pressure condition is from electricity.

The design output temperatures of the "chiller" are 45°F (evaporator) and as high as 130F (condenser). ECC's Helisorber was designed for applications with large DHW loads and constant (even if small) cooling loads. The design capacity for the unit involved in this project is 800 kBTU heating, and 25 RT chilling. As a simultaneous heating and cooling unit, it literally removes heat from places in the building where it is not wanted (specifically air-conditioning loads), and provides it to building applications where necessary (DHW). The Helisorber's cycle COPs are 1.60 (condenser – heating side) and 0.60 (evaporator – cooing side). When used primarily for heating applications, the relatively low efficiency of the evaporator is not relevant because it is essentially providing "free cooling" along with an otherwise highly efficient heating cycle.

The Helisorber is manufactured by ECC at their facility in Annapolis, Maryland. ECC's previous installations using this technology have spanned a range of industrial applications, such as commercial refrigeration using waste heat (Figure 5), however; it has never been "married" to a solar thermal system or used in this way in the hospitality industry.

**Figure 5: Previous Installation of a Gas Absorption Unit by Energy Concepts**

Photo Credit: Energy Concepts

With typical commercial boiler fuel efficiencies at around 80%, the HS-25’s COP of 1.60 represents a potential halving of the operating cost for DHW based on gas usage from the condenser side alone. While parasitic electric water pumping loads must be considered, the electricity saved by offsetting cooling on the evaporator side more than makes up for this.

### Putting Two Systems Together

A combination of the two systems was conceived and named the Solar Thermal Heat Pump (STHP) as a part of Chromasun’s initial offering to the market. While other industries could be interesting technology hosts, the hospitality industry has large daily needs for DHW and, particularly in California, usually has constant year-round needs for space cooling – even if small. This is combination is ideally suited for heating/cooling ratio of gas absorption, which is heating dominated. Firing the system using only solar was deemed unfeasible given the 24/7/365 requirements for hot water by hospitality. As previously mentioned, adding a small “co-fire” boiler to the system allows the system to guarantee hot water to the hotel at all times, even when the sun is down. Hotels also come in a range of sizes from small to large commercial facilities, often with ample roof areas, meaning a variety of targets exist in the industry.

Because the two technologies have never operated together, it was impossible to accurately predict the ultimate fuel savings. The thermal input from the sun, as well as how the hotel’s load profile would interact with the system were also unknown at the start of the project. Furthermore, other factors were identified that could affect ultimate fuel efficiency such as the size of thermal storage and the relative distances between system components. This project was conceived to provide a comprehensive data set to address these and other questions regarding the technology.

# CHAPTER 2:
# The Project and Its Goals

The major objectives proposed for this project were:

- Site Selection – the consideration of several possible hotel sites in the Southern California required balancing a variety of factors
- Hourly Modeling of MCT/Helisorber Integration – prior to design and construction, the likely performance, based on hourly modeling according to thermodynamic principles, should be demonstrated as likely to succeed
- Design / Build / Operate – the design, permitting, and construction of the STHP, including successful integration into the hotel's existing equipment
- Performance Monitoring – monitoring and verification of the STHP's results
- Technology Transfer (i.e. informing the industry) – activities to assess and inform the larger hospitality market of the project's results
- Developing Production Readiness – evaluation of conditions necessary to successfully sell this technology to the market.

The following sections discuss the outcomes of these objectives.

## 2.1 Demonstration on Paper

Modeling the STHP was completed, presented and accepted by the California Energy Commission in late 2015, at Critical Performance Review #1. The details of the model were discussed in the Critical Performance Review (CPR) report. In Table 2, a summary of 12 months of hourly performance is presented for a typical hotel, showing a net annual savings of nearly 30,000 therms and about 55,000 kilowatt-hours of electricity. If the hotel pays an average of $0.75 per therm for natural gas and $0.12 per kWh for the energy cost of electricity during STHP operation, the annual cost savings would be nearly $28,000 (Table 3).

**Table 2: Hourly Modeling Summary of STHP**

| STHP System Performance Summary (12 month cycle) | | Consumption Base Case (Required by Hotel) | Results With STHP Installed: From STHP via Nat. Gas | From STHP via Solar | From STHP Total | From Incumbent System | STHP & Incumbent | Savings via STHP |
|---|---|---|---|---|---|---|---|---|
| **Thermodynamic Energy** | Units | | | | | | | |
| **Hot Water** | | | | | | | | |
| DHW Demand | gallons | **6,981,926** | 5,979,504 | 843,033 | **6,822,537** | 159,389 | **6,981,926** | |
| DHW Heat Requirement | therms | **38,419** | 32,903 | 4,639 | **37,542** | 877 | **38,419** | |
| **Chilled Water** | | | | | | | | |
| CHW Supplied to Hotel | mm_BTU | | 179 | 1,266 | **1,445** | | | |
| **Utility Energy** | | | | | | | | |
| Natural Gas | therms | **54,884** | 25,302 | - | **25,302** | 1,253 | **26,555** | **28,329** |
| Electricity Offset (hotel chiller) | $kWh_E$ | - | 11,623 | 82,438 | **94,061** | - | | 94,061 |
| STHP Parasitic Electricity | $kWh_E$ | - | - | - | **39,437** | - | | (39,437) |
| **Net Electricity** | $kWh_E$ | | | | | | | **54,624** |

Source: Chromasun, Inc.

**Table 3: Cost Savings Summary (Typical Hotel)**

| **STHP System Cost Savings Summary** | |
|---|---|
| *Utility Costs* | |
| *Average Price of Natural Gas ($ / therm)* | *$ 0.75* |
| *Average Price of Electricity ($ / kWh)* | *$ 0.12* |
| Annual Utility Cost Savings | |
| Boiler - Natural Gas Cost Savings | $ 21,247 |
| Chiller - Electricity Cost Savings | $ 11,287 |
| Parasitic Loads - Electricity Cost | $ (4,732) |
| **Estimated Annual Net Utility Cost Savings** | **$ 27,802** |

Source: Chromasun, Inc.

## 2.2 Site Selection, Design, and Construction

Finalizing site feasibility was completed by considering a half dozen interested potential site hotels throughout Southern California Gas Company service territory. The JW Marriott at Desert Springs (a large golf resort, located in Palm Desert, California) was selected based on a variety of factors, including physical site conditions, hotel size, management interest and support, and proximity to a relatively larger solar resource (Figure 6). Working with Marriott Hotels International also sets a strong foundation for the ultimate commercial success of STHP technology.

**Figure 6: Project Site – JW Marriot at Desert Springs, Palm Desert, California**

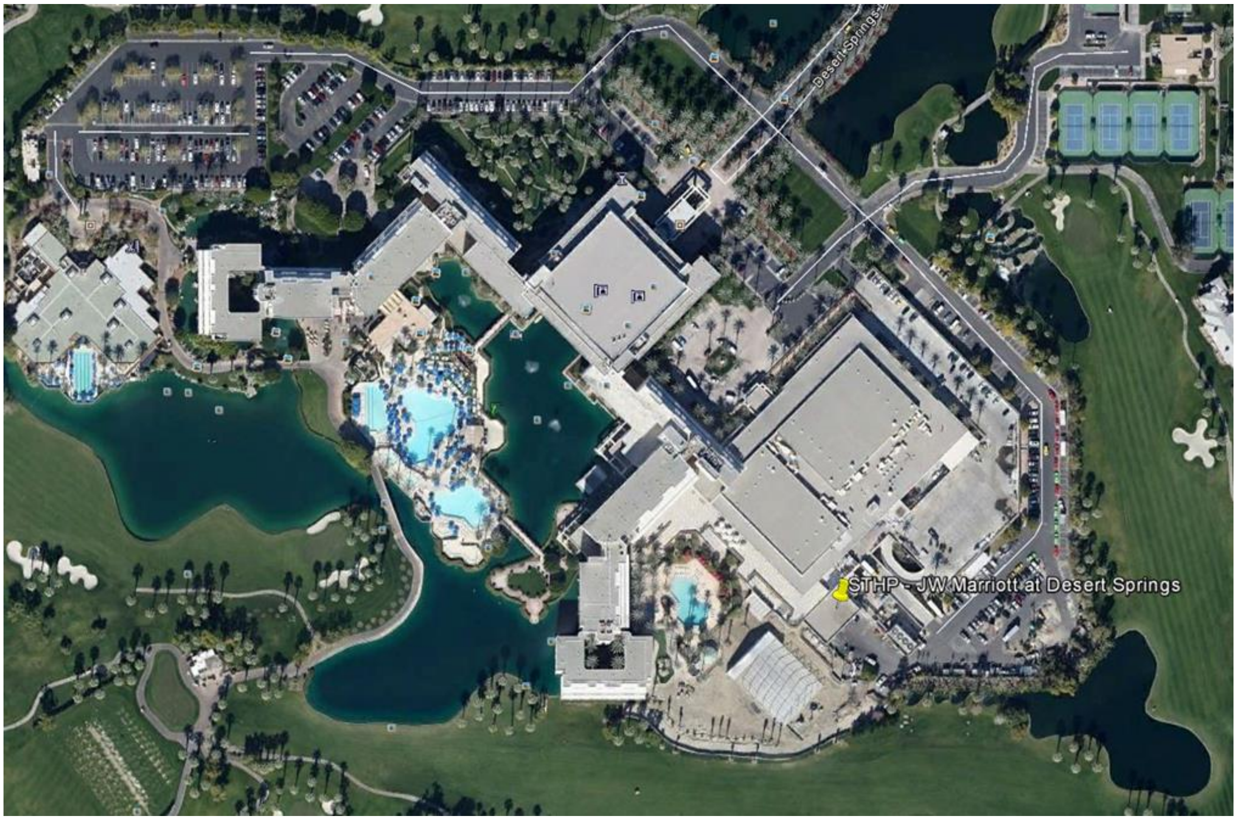



Photo Credit: Google Earth

The STHP Design Team consisted of Chromasun, Energy Concepts (HS-25 manufacturer), Keystone Energy Solutions (project engineer), and SunWater Solar (general contractor). The City of Palm Desert was the authority having jurisdiction, and Fazekas and Associates provided overall mechanical review. The building permit was obtained fall 2015, and construction began in early 2016. Retrofit Technologies, a local mechanical contractor, which has extensive experience with the JW Marriott's mechanical systems, was selected to perform the major mechanical work.

Major construction was completed by late summer 2016, coinciding with the hotel's slower season for occupancy (during the hot weather). Construction activity focused on three main areas, including the roof over the loading dock where the MCTs were installed (Figure 7), the chiller room where he HS-25 and pump skid was installed (Figure 8), and the boiler room where a 3,000 gallon DHW tank was retrofitted for thermal mass storage purposes (Figure 9).

**Figure 7: MCT Solar Thermal Panels Installation Complete**

Photo Credit: Chromasun, Inc.

**Figure 8: HS-25 Helisorber Installation Complete**

Photo Credit: Chromasun, Inc.

**Figure 9: DHW Tank Room (Retrofit Complete - Far Tank)**

Photo Credit: Chromasun, Inc.

The City of Palm Desert provided final inspection of the project in August, and initial operations commenced shortly thereafter.

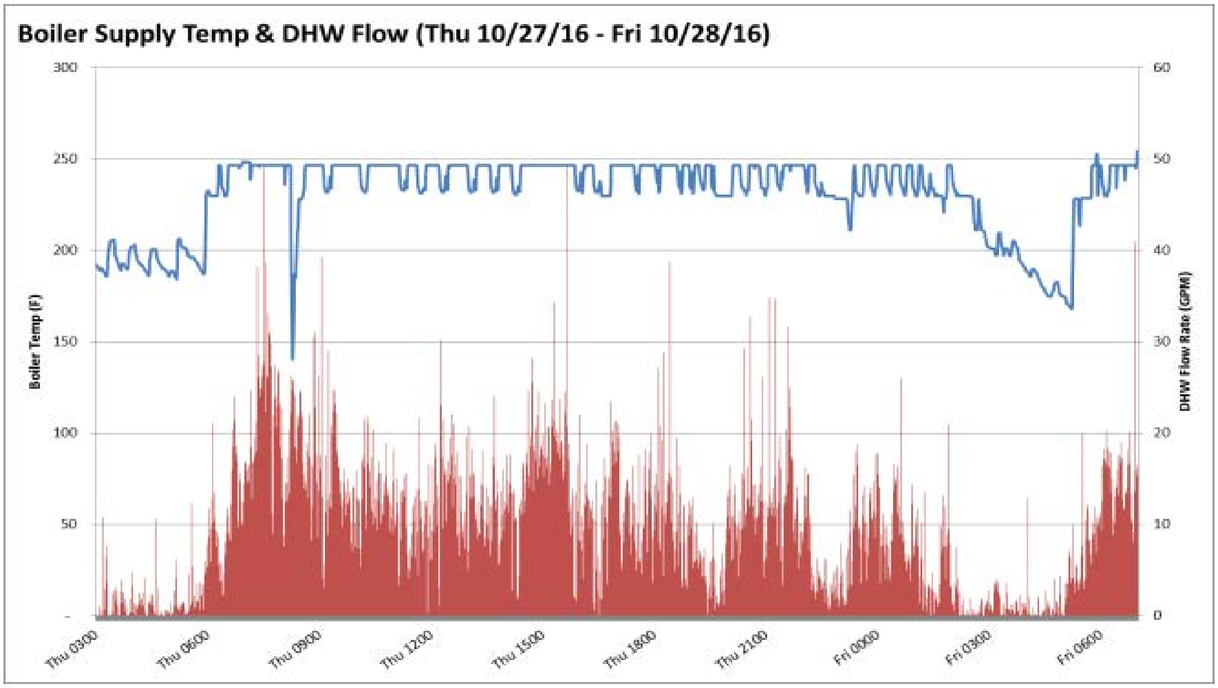
## 2.3 Operations

Despite the necessary end of the contracting period, Chromasun will continue to operate the STHP for at least 24 months following construction. Obtaining operational data is important to the project's overall goals of commercialization. The system's mechanical contractor during construction, Retrofit Technologies will provide locally-based operations and maintenance support, along with the original equipment manufacturer. Throughout the fall and winter of 2016, the STHP has operated successfully for short periods of time, but has had several commissioning-related issues as discussed preventing continuous operations and/or data collection.

### 2.3.1 Short-Cycling

After initial commissioning and installation of monitoring and validation instrumentation, a period of technical adjustments took place, and continued into the fall of 2016. The hotel's DHW load has appeared to be significantly lower than had previously been measured prior to the design process. The STHP has a capacity to deliver of up to 28,000 gallons per day of domestic hot water. The hotel's load has proved to be significantly smaller (in the 10,000 GPD range). Discussions with hotel engineering staff were undertaken to identify the underlying cause of the smaller load. In one case, a valve in the pipes leading to the restaurant/kitchen areas appeared to have been switched to a different position. These discussions are continuing and there are some remaining questions to be addressed regarding the hotel's piping layouts that may have been altered during mechanical room renovations in 2012.

**Figure 10: Short-Cycling Situation**

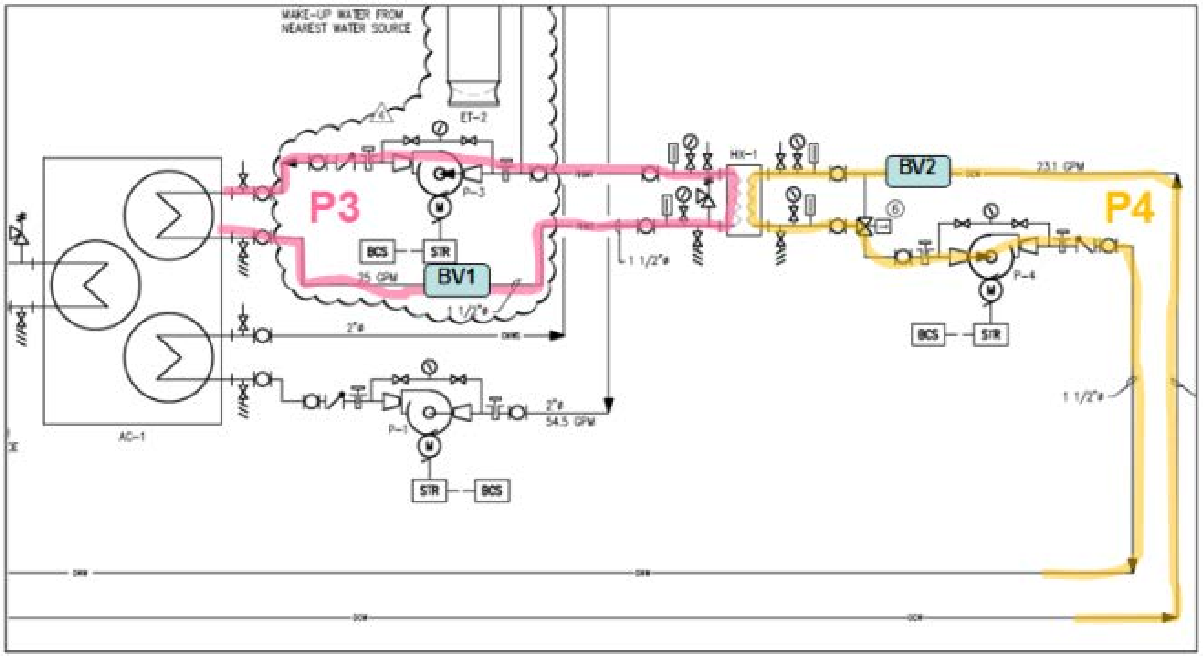



Source: Chromasun, Inc.

The smaller DHW load has caused the HS-25 to "short-cycle", specifically frequently switching on and off as it heats up the DHW thermal storage tank to the required set-point (Figure 10). Absorption systems should ideally operate as continuously as possible so as to avoid thermal losses which are introduced every time a system is restarted from a cold condition. This maximizes system performance. Ultimately, the system can be designed to meet any reasonable capacity found in small, medium, or large hotels. However, getting the size right in the original design is clearly important.

The design team convened several calls during the fall of 2016 to assess the situation for this particular installation, and to evaluate potential solutions. They decided to install a pair of controllable valves on the primary and secondary DHW pump loops (P-3 & P-4, shown as BV1 and BV2 in Figure 11). These are remotely controllable, as well as automatically by programmer logic designed by Energy Concepts. Adjusting these valves will effectively change the STHP capacity, reducing it from its original size. As of the end of first Quarter 2017, these valves were installed, but not fully operational due to an air-bubble problem, slated to be resolved in April.

**Figure 11: Short-Cycling Solution**




Source: Chromasun, Inc.

## 2.3.2 Ammonia Leak Incident

On December 10, 2017, following routine maintenance on the HS-25, a small ammonia vapor leak occurred, resulting in an emergency shutdown of the system. The cause was traced to a faulty pressure switch component erroneously labeled by the manufacturer as ammonia-certified. Energy Concepts had representatives on-site soon after the incident. The situation and analysis of the problem, along with corrective action steps were fully documented to the hotel's management and the Energy Commission in a report shortly thereafter. The hotel remains supportive of the project, and after certain approved corrective measures were taken, the system was restarted a few weeks later.

## 2.3.3 Performance & Monitoring

Owing to various commissioning and operational issues previously cited, STHP performance data is presently incomplete (as of March 2017). The short-cycling situation has yielded only a few periods where hotel DHW demand was sustained and sufficient enough to approximate the design load, resulting in STHP operation long enough to measure performance. Tables 4 and 5 are samples of contiguous hour-long periods of operation, one during daylight, and the other at night. The performance for these samples is measured from the DHW side only (not including chilled water), and shows the amount of hot water delivered to the hotel relative to the gas consumed by the co-fire boiler. During the daylight period, the Condenser Cycle COP (shown here as 1.65) would be expected to exceed the system's design coefficient of performance (COP) target of 1.55, owing to the "free heat boost" being provided by the solar thermal (MCT) system. A somewhat lower sun-down period COP (1.43) is also to be expected.

**Table 4: Condenser Performance Spot Analysis (Daylight)**

| HS-25 Condenser Performance Analysis | | |
|---|---|---|
| | | |
| Period Start | 10/28/2016 (Fri) 15:00 | |
| Period End | 10/28/2016 (Fri) 15:59 | |
| | | |
| Total DHW Consumption | 1,024 | Gallons |
| | 17.07 | Avg GPM |
| Total Heat Supplied | 340,912 | BTU |
| Total Gas Consumed | 207,019 | BTU |
| **Condenser Cycle COP** | **1.65** | |

Source: Chromasun, Inc.

**Table 5: Condenser Performance Spot Analysis (Night)**

| HS-25 Condenser Performance Analysis | | |
|---|---|---|
| | | |
| Period Start | 10/27/2016 (Thu) 21:30 | |
| Period End | 10/27/2016 (Thu) 22:29 | |
| | | |
| Total DHW Consumption | 659 | Gallons |
| | 10.98 | Avg GPM |
| Total Heat Supplied | 181,752 | BTU |
| Total Gas Consumed | 126,730 | BTU |
| **Condenser Cycle COP** | **1.43** | |

Source: Chromasun, Inc.

These data are not offered as final representative proof of system performance, but more as a "spot check" to ensure that the STHP is capable of delivering the expected performance. On-going performance data will be collected and made available to the Energy Commission and other interested parties in supplemental reports.

# CHAPTER 3:
# Moving Forward Towards Commercialization

## 3.1 Development Potential

The solar thermal heat pump has a large potential to make positive environmental and economic impacts for California, as well as hotel property managers and owners. There are more than 5,000 hotels in California; and more than 52,000 in the United States, representing some five million rooms. Domestic hot water consumption is generally one of the largest building energy loads after air conditioning, and is very prevalent in hospitality-oriented buildings, being central to hotel operations. In the US, 70% of all rooms are controlled by hotel chains, and Marriott International is presently the world's largest such organization, with more than 6,000 properties. In recent years, demand has continued to outstrip hotel room supply; and two thirds of the industry's growth has been in the upscale and mid-upscale market segments.

STHP applications are likely to be economically strong where buildings have relatively high hot water loads. Besides hospitality, this would include college dormitories, prisons, and other institutions which house large numbers of people in either short or long-term situations. Chromasun's initial focus on hospitality in general and Marriott in particular, is driven by strategic market development considerations. These include relative homogeneity in facilities, as well as a large concentration of facilities under a single umbrella which enables easier communications and product development.

Hotels, particularly the larger properties, rated 4 and 5 stars, also compete, in part, on the basis of environmental leadership. It is not uncommon for a facility's environmental story to operate as a "tie-breaker" when booking conventions and other large gatherings. These businesses also operate in a competitive industry with relatively narrow profit margins. A technology initiative such as the STHP, generates sizeable utility cost savings and provides significant competitive advantages.

Chromasun believes that aligning this research and technology development project with the interests of one of the world's most visible hotel management systems will ensure strong market acceptance once the product is market-ready.

## 3.2 Technology Transfer

- ACHR News: In September 2015, the STHP was featured as a part of their annual roundup of "new technologies" for the HVAC business. The article highlighted the major benefits and features of the STHP, including the fuel efficiency, and a description of the key technologies. It also discusses the CEC's role and the industry's context for why the STHP is poised to lead to such a large leap in cost savings.

- Marriott International Engineering Conference (spring 2015): Marriott holds a tri-annual conference for the leadership of the engineering departments at its various properties world-wide. Because of the project's early status, Chromasun chose not to make a formal presentation. However, since the conference was held at the Palm Desert facility, numerous informal discussions still took place (driven by the property's engineering director), and Chromasun received several inquiry phone calls as a result. It is expected that Chromasun will make a major effort to be visible and present at the next conference.

- Energy Concepts made a formal presentation at the ASHRAE 2017 conference in January 2017 about the STHP system. The session was well attended by specifying engineers and other channels that will be important for recommending the opportunity to clients who are in the midst of mechanical room upgrades.

- Marriott publishes an internal periodic newsletter for its engineering department heads. Chromasun expects to provide information and data for the next issue coming out in mid-2017.

- Among the benefits of hospitality trade associations to its members, are insights on how to operate more profitably. Chromasun will work with the California Hotel and Lodging Association to provide information about the STHP, including webinars for its members throughout the state. There also plans to expand the discussion to the national and international levels by reaching out to the American Hotel and Lodging Association (www.ahla.com/), and its European (www.hotrec.eu/) and international (http://ih-ra.com/) counter-parts.

## 3.3 Conclusions and Recommendations

The Solar Thermal Heat Pump project successfully demonstrated the basic functionality of the technology in a live commercial setting. The project team analyzed and worked to solve important obstacles that were encountered. The opportunity to build the system and collect operational data with the cooperation and support of a major targeted customer of the technology (Marriott) is critical for developing the product and its business case.

Besides operating the STHP and collecting performance data at JW Marriott at Desert Springs, Chromasun will also pursue follow-on opportunities for the system. A major unanswered challenge posed by the market five years ago was, "prove it will work." The STHP project sponsored by the California Energy Commission and the Southern California Gas Company has provided an important platform from which to answer that challenge. During the coming months, Chromasun will complete the work of gathering the performance data, and re-develop the business case for advancing the technology in the hospitality market and beyond.

# GLOSSARY

| Term | Definition |
|---|---|
| STHP | solar thermal heat pump |
| Gas Absorption | A thermodynamic process driven by two substances which attract each other at lower (room) temperatures, and repel each other at higher temperatures. This difference creates pressure differences which can be exploited to drive a heat pump cycle |
| DHW | domestic hot water – used for showers, laundry, kitchen/cooking, cleaning, etc. Typically around 120 – 140°F, depending on end-use. |
| CHW | chilled water – used for air-conditioning at around 45°F, typically it is circulated throughout a building in pipes and heat-exchanged in air-handling units to cool the air. |
| Energy Commission | California Energy Commission |
| MCT | Micro-Concentrator – Chromasun's concentrating solar thermal panel |
| HS-25 / Helisorber | The gas-absorption machine manufactured by Energy Concepts |
| ECC | Energy Concepts Company – maker of the HS-25. |
| kW / kWh | kilo-watt or kilo-watt-hour: measures of energy capacity and quantity (respectively) |
| MWh – TH | mega-watt-hour – thermal: a quantity of heat-based energy |
| $NH_3$ | Chemical notation for ammonia |
| $H_2O$ | Chemical notation for water |
| COP | co-efficient of performance |
| AFUE | average fuel utilization ffficiency: the amount of energy received for the amount of energy utilized. |
| Condenser | A part of the HS-25 (gas absorption unit) that produces DHW |
| Evaporator | A part of the HS-25 (gas absorption unit) that produces CHW |
| Bar | A pressure measurement. 1 Bar is 1 atmosphere of pressure (sea level) |